Applying Shainin's Tools to Process Improvement for Reducing Cracking Defect of Sanitary Product

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Abstracts: The objective of this research attempt is to implement the DMAIC (Define, Measure, Analyze, Improve, Control) approach, a part of the Six Sigma methodology, in order to diminish the loss of sanitary ware during the production process. Specifically, this study focuses on addressing the issue of cracking defects that often occur in the production of sanitary wares after the firing process. Cracking defects manifest as gaps on the surface of sanitary wares, resulting in nonconforming and aesthetically inferior products. The AG27 Model, a highly demand toilet bowl, was selected as the case study due to its significant occurrence of cracking defects, accounting for 20% of the total defective units. The research utilizes the Six Sigma methodology in conjunction with Shainin's tools to identify the root causes and enhance production yield. The employed Shainin's tools include the Family of variation (FOV's), Concentration chart, Paired comparison, and Better and current (B vs C). The primary focus area of investigation involves the variation in the forming process and the design of the plaster mold. Through the use of the concentration chart, it was determined that the cracking defects predominantly appear along the border line between the rim and body of the toilet bowl. Subsequent experiments, based on paired comparison, confirmed that the design of the border line, which incorporates a hollow body shape, and the potential degradation of mold quality due to frequent use, were the two significant factors contributing to the cracking defects. In order to address these issues, a new design was implemented to enhance the connection between the rim and solid body of the AG27 toilet bowl. The practicality of this solution was validated through the utilization of the B vs C tool during the improvement phase. As a result, the occurrence of cracking defects decreased from approximately 4.0% to 1.92% during the control phase, representing a potential reduction of defects by over 50%.

Keywords: Shainin's tools, Paired Comparison, Family of Variation, Defect Reduction.

1. INTRODUCTION

The Currently, the process of globalization has led to intensified competition and rapid changes in various industries, placing significant pressure on businesses. In response to this heightened competitive environment and advancements in technology, there is an increasing demand for continuous business improvement, particularly in the realm of operational activities [1]. Addressing quality and reducing costs are vital areas that require attention. Consequently, several operational strategies such as Total Quality Management (TQM), Lean Manufacturing, and Six Sigma have gained prominence in managing these challenges within organizations [2-4]. The Six Sigma methodology, which focuses on quality improvement, has gained recognition in both practical and academic literature [5-7]. Within manufacturing processes, the DMAIC (Define, Measure, Analyze, Improve, Control) approach, as an effective problem-solving process, is employed to enhance quality issues.

This research attempt to apply the DMAIC approach, in conjunction with Shainin's Tool, to the production of sanitary ware. The selection of the AG27 model of toilet bowl as the focus of this study is based on the high incidence of quality-related losses. Specifically, the problem of cracking is identified during the define phase. The measurement phase concentrates on determining the precise location of fracture in the AG27 model, followed by an investigation into the root causes by applying simply tools of Shainin at shop-floor. Such practical tools are Family of Variation (FOV's), Paired Comparison and B vs C [8-10]. Subsequently, the improve phase is dedicated to devising a solution. By implementing this methodology to reduce defects, the production yield can be sustainably increased.

2. LITERATURE REVIEWS

2.1. Six Sigma Way

The Six Sigma methodology is a systematic approach to process improvement, which is implemented through a series of projects aimed at achieving high levels of process effectiveness [11-12]. Originally developed as a statistical measure, it was initially introduced as a quality operation strategy at Motorola and General Electric. Over time, it has evolved into a comprehensive methodology for problem-solving and process improvement [13]. Six Sigma operates on three distinct levels [14-15]:

1.   Metric: The quality level of Six Sigma is defined as 3.4 Defects Per Million Opportunities (DPMO), with the opportunity counts adjusted to account for the complexity of the product or process.

2.   Methodology: Six Sigma provides a structured problem-solving roadmap and employs various tools such as the Define, Measure, Analyze, Improve, and Control (DMAIC) framework, as well as the Design for Six Sigma (DFSS) methodologies.

3.   Philosophy: Six Sigma emphasizes the reduction of variations in business processes and promotes data-driven decision-making with a strong focus on meeting customer needs and expectations.

Due to its ability to consistently reduce defects within an organization, Six Sigma has gained significant prominence in the management practices of many multinational corporations, thereby exerting a dominant influence on management thinking and strategy [14].

2.2. DMAIC Methodology with Shainin's tool

The integration of Six Sigma and Shainin's tools offers a powerful approach to problem-solving and process improvement. Six Sigma, a data-driven methodology, aims to reduce defects and improve overall process performance, while Shainin's tools provide practical problem-solving techniques to identify and address the most critical issues. By combining these two approaches, organizations can achieve enhanced results in quality and operational efficiency [16-19].

Six Sigma associated with Shainin concepts follows a structured framework known as DMAIC (Define, Measure, Analyze, Improve, Control) to guide improvement projects as shown in Figure 1 [10]. In the Define phase, the project goals and problem statement are clearly defined, aligning with the organization's strategic objectives. Shainin's Red X technique can be employed during this phase to identify the most critical problem or defect that needs immediate attention.
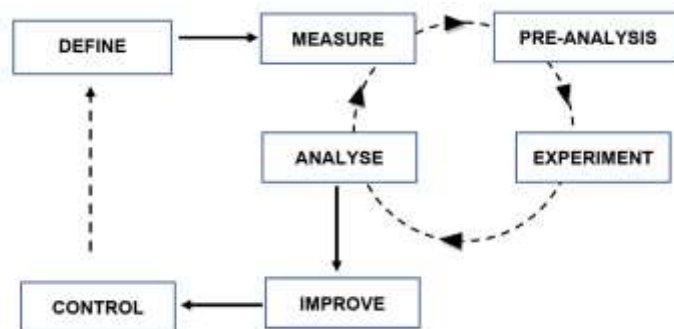

Figure 1. DMAIC Methodology with Shainin's Tools [10].

During the Measure phase, data collection and measurement techniques advocated by Six Sigma are utilized to quantify the current process performance. Shainin's tools, such as Component Search and Variables Search, can be applied to identify critical process parameters and potential sources of variation that significantly impact the problem.

In the Analyze phase, statistical analysis methods provided by Six Sigma, such as hypothesis testing and regression analysis, are employed to understand the relationships between process inputs and outputs. Shainin's tools, such as the B vs C and the Paired Comparison, complement these analyses by isolating specific variables and determining their impact on the problem.

The Improve phase focuses on developing and testing potential solutions to address the identified problem. Six Sigma's DMAIC framework guides the selection and implementation of improvement strategies. Shainin's tools, such as the Variable Search, can be used to identify specific variables causing defects and guide improvement efforts in a targeted manner.

The Control phase ensures that the improvements achieved during the previous phases are sustained over time. Six Sigma's control charts and statistical process control techniques are applied to monitor and control process performance. Shainin's tools, such as the Red X and Poka-Yoke, can assist in maintaining the gains achieved during the improvement phase by continuously monitoring critical variables and implementing error-proofing mechanisms.

By integrating Six Sigma and Shainin's tools, organizations can benefit from a comprehensive problem-solving approach that combines statistical analysis, process understanding, and practical problem-solving techniques [20-21]. The data-driven nature of Six Sigma helps in identifying root causes and implementing sustainable solutions, while Shainin's tools provide a practical focus on the most critical issues.

3. METHODOLOGY

3.1. Define Phase

The occurrence of a cracking defect is a prevalent issue in the manufacturing of sanitary ware, often observed subsequent to the firing process. This defect manifests as a fracture on the surface of the ware, as depicted in Figure 2.

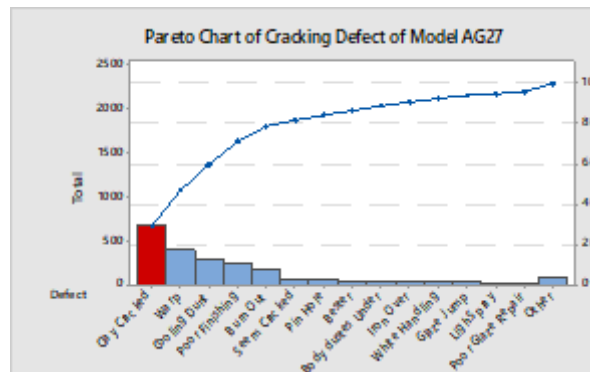**Figure 2.** Cracking Defect of a Sanitary Ware

Figure 3. Pareto Chart of Defects (AG27 model)

This quality issue has significant implications for production losses. In this study, the AG27 model is selected as the case due to its high production demand. The pareto chart of losses, as represented in Figure 3, indicates that the cracking problem constitutes 20% of the total defects. Thus, the primary objective of this research, established during the define phase, is to mitigate the occurrence of cracking defects specifically in the AG27 Model.

3.2. Measure Phase

The focus of this study is directed towards the forming, glazing, and firing processes, as they are closely associated with the occurrence of cracking defect. From the data collection on defects resulting from cracking in the selected sanitary ware model, the focus was on the analysis of the non-conformings generated during the grade separation process (Glost Inspection). The records were documented in a Concentration chart over a period of two months. Once a sufficient amount of data was obtained, these records were further analyzed and compared within the context of the Family of variation (FOV's) methodology to identify areas of significant variation in variables that may be the underlying causes of the observed defects in both the Product Family and the Process Family.

Table 1. Family of Variation for Cracking Defect

FOV's	Sources of Process Variation	Observed point	Result
Product family	Point to Pont	Same Area	* Difference
	Area to Area	Same Side	No difference
	Side to Side	Same Mold	No difference
	Mold to Mold	Same Bank	No difference
Process family	Caster to Caster	Same Model	No difference
	Model to Model	Same Sprayer	No difference
	Sprayer to Sprayer	Same Setter	No difference
	Setter to Setter	Same Kiln	No difference
	Kiln to Kiln	Same time	No difference

Through the utilization of a variation analysis technique, it has been determined that the occurrence of cracking in the sanitary ware can be identified through the application of Shainin's concentration chart. This analysis has resulted in the identification of 18 distinct locations where cracking defects are observed. Subsequent examination of the defective sanitary wares has revealed that a significant proportion of the defects are discovered in the 14UL location, which corresponds to the connection between the rim and body of the ware, as illustrated in Figure 4.
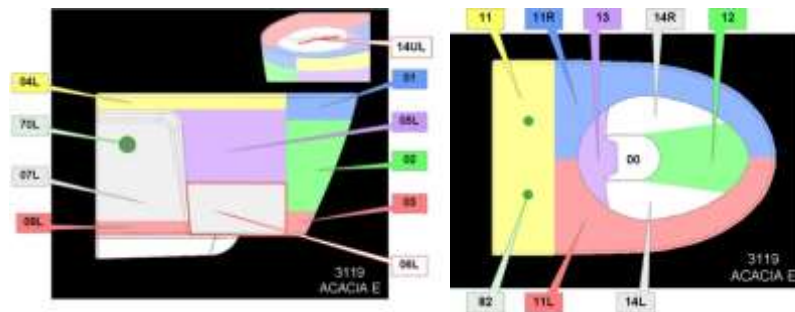

Figure 4. Location 14UL of Cracking in Concentration Chart

3.3. Analyze Phase

3.3.1. Investigate Cross Section of Cracking Defect

To investigate the defect that arises from the mentioned concern on location 14UL, a point-to-point comparison was conducted. The analysis focused on the characteristics of the fracture surface after the firing process. The cross-sections were performed on the discovered damaged work-piece, specifically at the position of the fracture, as shown in Figure 5. Subsequently, these sections were magnified to examine the presence of cracks and determine the depth of the resulting break. It was observed that the fracture occurred between layers at the interface between the edge portion and the body.
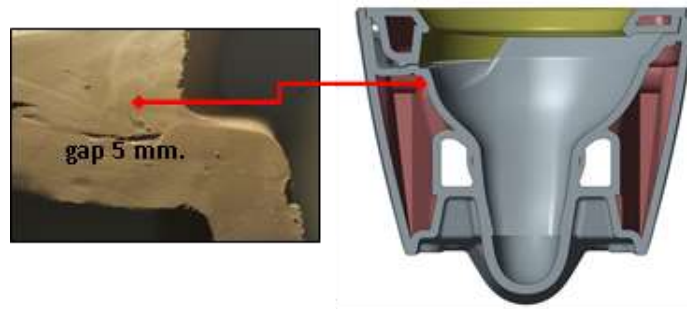
Figure 5. Cross Section of Connection Between Rim and Body Ware

3.3.2. Paired Comparison of BOB and WOW Design

Through brainstorming sessions with the team members, the characteristics of the cracking defects resulting from the suspected causes were explored. By comparing the areas in question, specifically the connection between the rim and the body of the mold sanitary ware, using an Area to Area analysis, it was found that the gap was approximately 5 millimeters in size at the 14UL position. Further investigation and experimentation were conducted by comparing the quantities of defects occurring during the same time period between two similar-designed sanitary ware models produced in close proximity within the manufacturing process. Notably, a significant difference in defect quantities was observed, with the AG27 model exhibiting a defect rate of about 4.0% compared to the AG405 model, which had a defect rate of 0.6%. The AG27 model was classified as a Worst-Of-Worst (WOW) condition, while the AG405 model was classified as a Best-Of-Best (BOB) condition in the comparative analysis.

Upon examining the characteristics of the differences in the connection between the rim at the 14UL position in both models, it was observed that the AG405 model had a robust structure, with a thicker clay body at the rim's edge, referred to as a Rim solid design, connecting to a similarly designed body section with a solid structure. This is illustrated in Figure 6 (b). Conversely, the AG27 model had a thinner clay body at the rim's edge, also in a Rim solid design, connecting to a body section with a hollow structure, referred to as a Body hollow design. This section exhibited a less robust structure, which could potentially weaken after the rim connection, as shown in Figure 6 (a).
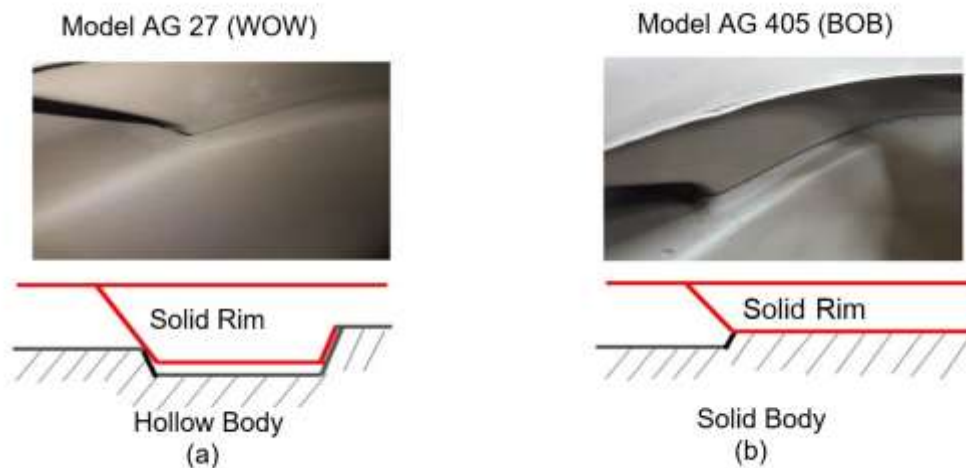

Figure 6. Design of (a) AG27 (WOW) vs (b) AG405 (BOB)

In this step, the data obtained from the experimental product tracking is analyzed to assess the defectiveness of the 14UL position using Shainin's technique of Paired Comparisons. The method involves comparing the Best-Of-Best (BOB) pieces with the Worst-Of-Worst (WOW) pieces using the Turkey Test theory, which compares the differences between paired population means. The samples are independently selected, allowing for selection from populations of equal or unequal sizes. The Total end-count, the sum of the end count values, is calculated. If the Total end-count is greater than or equal to 6, it indicates a confidence level of 90% or higher, suggesting the significance of the considered variables or factors and their impact on product quality. Conversely, if the Total end-count is less than or equal to 5, it indicates that the considered variables are not statistically significant or have no effect on quality.

Six pairs of sanitary ware products are selected for analysis, comprising six products from the Rim solid design connected to Body solid design process and six products from the Rim solid design connected to Body hollow design process. The samples are randomly paired, and the quality of the sanitary ware products is evaluated after firing process, as shown in Table 2.

Table 2. Paired Comparison of BOB and WOW design

Pair No.	Solid Rim connect to Solid body design (BOB)	Solid Rim connect to Hollow body design (WOW)
1	No cracking (0.0 mm.)	No cracking (0.0 mm.)
2	No cracking (0.0 mm.)	No cracking (0.0 mm.)
3	No cracking (0.0 mm.)	No cracking (0.0 mm.)
4	No cracking (0.0 mm.)	Cracking (6.2 mm.)
5	No cracking (0.0 mm.)	Cracking (5.4 mm.)
6	Cracking (5.3 mm.)	Cracking (6.0 mm.)

The experimental results of the cracking defects in the 14UL position of the sanitary ware are organized to calculate the Total end-count. From Table 2, the end count for the BOB design is found to be 4, while the end count for the WOW design is 2. The Total end-count, which sums up the end count values, is 6, indicating that the Rim solid design connected to the Body solid design process is statistically significant with a confidence level of 90%.

3.4. Improve Phase

In this process, it is a step of confirming the major cause obtained from the experiment in order to ensure that the cause received sustained improvement. The Shainin's tool is used to analyze B vs C, which means comparing a better process with the current process (Better vs Current, B vs C). It is a tool used to prove problems encountered in the product or production process that have been modified and improved to demonstrate or confirm that they are better than the original process. It involves selecting one pair of processes or options, with the currently used process being the condition for process C (Current), and the new process or the process expected to be better being the condition for process B (Better). This serves as a tool for reviewing or verifying the results of factors (Verification Tools) and making decisions on which product or process is superior in terms of quality. The quality and confidence of the B vs. C method are determined at a significance level of 10% (or 90% confidence). The advantage of this method is that it is easy to compute and requires a small sample size for testing.

From the experiment comparing the new rim design with the previous rim design, which consists of a solid rim connected to a solid body (BOB) and a solid rim connected to a hollow body (WOW), 28 sets of molds (one casting table) were modified. From the experiment comparing the Better condition (B) with the Current

condition (C), as shown in Table 3, the products were divided into 3 lots, each lot containing approximately 180 pieces. After the firing process, the data on the results of inspecting and screening the products were collected, and the defects of cracks in the 14UL position were found.

Table 3. B vs C for Confirmation of Improvement.

	No. of Inspection (pcs.)	No. of Cracking (pcs.)	%Defective
Better condition (B)	220	3	1.4% (no.1)
	180	4	2.2% (no.2)
	200	5	2.5% (no.3)
Current condition (C)	186	18	9.7% (no.4)
	160	17	10.6% (no.5)
	200	25	12.5% (no.6)

From Table 3, the order of the percentages of defects in the 14UL crack position was obtained after arranging the data. It was observed that the order obtained after arranging did not violate the no-overlap rules, which means there was no overlap between the conditions in B vs C. When the total end count was calculated, it was found to be 6 (no.6), indicating that condition B is better than condition C with a 90% confidence level.

3.5. Control Phase

From the main root cause obtained from the measure and analyze phase, it is necessary to expand the experimental results in the normal production process of the product in order to validate and realize the financial benefit of the solution. This is achieved by redesigning a structurally weak connection at the 14UL position, which is the weak connection point of the solid rim and hollow body ware (WOW). The new design mold involves connecting a solid rim to a solid body (BOB). In stage 1, experimental testing and design modifications were gradually conducted, comparing the improved mold design to the current process. It was found that the proportion of cracking defects at the 14UL position decreased, leading to the expansion of the experimental testing and modification of the plaster mold. In Stage 2, during the production process using the actual production molds, all molds were replaced. The defect rate decreased by an average of 1.92% of the total production, as shown in Figure 7.
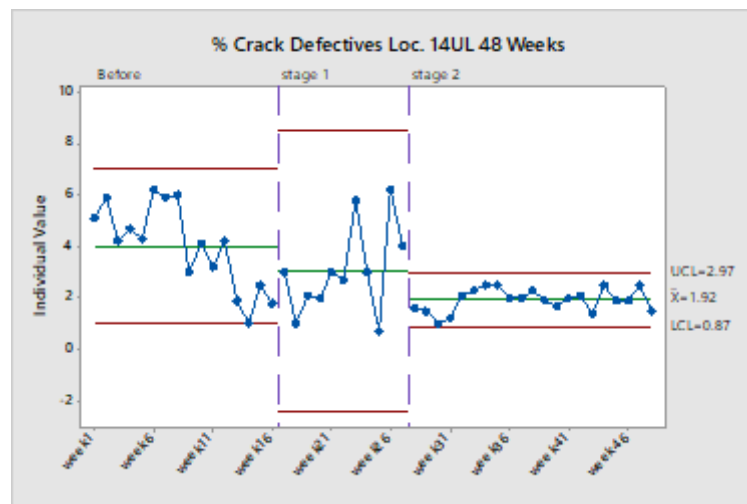

Figure 7. % Defectives of AG27 Before and After Improvement

CONCLUSIONS

The production of sanitary ware is a highly variable process due to the significant variations in raw materials and the wide range of product models, including intricate designs. Among the major quality issues faced in this production are cracking defects, which result in significant losses during the manufacturing process. To address this problem efficiently, the Six Sigma Methodology's DMAIC approach is implemented. In this study, the AG27 model of toilet bowls is selected as a case study. The forming, glazing, and firing processes are the focal points of investigation to identify the root causes of cracking. The Shainin's tool, Family of Variation, is employed to narrow down the potential causes to the area where cracking occurs, specifically the border between the rim and body of the sanitary ware. A comparison is made between the cracking observed in the AG27 model and a superior model, AG405. The findings indicate that the hollow design of AG27 is a major contributor to the cracking defect. To confirm the root cause with a 90% level of statistical confidence, paired comparison of Shainin's tools, specifically B vs C, is utilized. The primary solutions proposed are the redesign of Model AG27, incorporating a solid rim and body based on the design used in AG405. Additionally, measures are suggested to enhance the quality control of the plaster mold to prevent cracking during the firing process. These solutions lead to a reduction in the defect rate from 4.0% to approximately 1.92%, representing a significant decrease of over 50% in the cracking defect problem. It should be noted that Shainin's tools, renowned for their practical implementation at the shop floor level, can be effectively integrated into the DMAIC framework for process improvement. Numerous applications in manufacturing have demonstrated their benefits, making them valuable tools across various industries for enhancing production efficiency.

ACKNOWLEGDEMENT

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